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RELIABILITY AND MAINTAINABILITY BLOCK DIAGRAMS AND MATHEMATICAL--ETC(U)

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Flight Safety Reliability
Mission Reliability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document defines the maintainability block diagrams and math models and the reliability block diagrams for the sink rate delay/improved in-water stability system for helicopters (Helicopter Flotation System (HFS)). These diagrams and models serve as a basis for estimating the effectiveness of the HFS as a survival system and will be used in allocation, prediction, and failures modes and effects analysis.

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## ABSTRACT

This document defines the maintainability block diagrams and math models and the reliability block diagrams for the "Sink Rate Delay/Improved In-Water Stability System for Helicopters" (Helicopter Flotation System) (HFS). These diagrams and models serve as a basis for estimating the effectiveness of the Helicopter Flotation System as a survival system and will be used in allocation, prediction, and failure modes and effects analysis.

## KEY WORDS

Block Diagram
Math Model
Hardware Breakdown Structure
Planned Maintenance
Special Inspection
Phased Inspection
Maintenance Downtime
Turnaround Inspection
Flight Safety Reliability
Mission Reliability
Maintenance Malfunction Reliability

## ABBREVIATIONS

| | |
|---|---|
| HFS | Helicopter Flotation System |
| WRA | Weapon Replaceable Assembly |
| BCM-9 | Beyond Capability of Intermediate Maintenance (Item condemned) |
| BCM 1-8 | Beyond Capability of Intermediate Maintenance (Item shipped to depot level) |
| MH/FH | Manhour per flight hour |
| $\lambda$ | Maintenance action rate per 1000 flight hours |
| ET | Elapsed Time |
| CREW | Average number of men required for the maintenance action |
| TURNAROUND | Performed every two flight hours and $\lambda$ = 500/1000 FH |
| SPECIAL | Performed every 28 days or 38.4 flight hours and $\lambda$ = 26.042 per 1000 flight hours |
| PHASE | Performed every 400 flight hours and $\lambda$ = 2.5 per 1000 flight hours |
| HBS | Hardware Breakdown Structure |

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## LIST OF FIGURES

## 1. MAINTAINABILITY BLOCK DIAGRAM AND MATHEMATICAL MODEL

The Helicopter Flotation System (HFS) installation, by its nature as survival equipment, is not normally exercised during routine flight operations and hence its impact on overall system operational readiness may be considered as insignificant. This parameter, considered herein as synonymous with availability, is assessed by the following model and later quantified as a part of maintainability allocations and predictions. Preventive or scheduled maintenance comprises the major portion of the installation maintenance burden and is addressed at both organizational and intermediate levels of maintenance by the model. However, preventive maintenance at the intermediate level is not presently anticipated. Corrective maintenance is treated in a like manner and as a result the block diagram and maintainability model can be used to determine the character and magnitude of the HFS installation maintenance downtimes and maintenance support demands at the organizational and intermediate levels of maintenance.

## 2. HFS HARDWARE BREAKDOWN STRUCTURE (HBS)

The HBS affords a graphic display and interrelationship of the end item subdivided into successively smaller units. Each unit is identified with a summary number conforming to the requirements of MIL-STD-780, "Work Unit Codes and Maintenance Engineering Analysis Control Numbers (MEACNS) for Aeronautical Equipment; Uniform Numbering System". This number is used for Logistic Support Analysis (LSA) identification during design and development, and for maintenance reporting during operational use, thus closing the loop of Allocation, Prediction, Demonstration and Evaluation.

Figure 1 shows the HFS installation interfaced with a segment of the existing HBS of the H-46 helicopter as contained in NAVAIR 01-250HD-8, "Work Unit Code Manual H-46 Aircraft". As indicated, the HFS as presently envisioned consists of three major installations: Nose Flotation, Stub Wing Flotation and Controls. With the exception of the access panels, the Weapon Replaceable Assemblies (WRA's) of the flotation installation are identical. The added electrical components and wiring are considered in this model, recognizing that operational maintenance would be reported under the Electrical Work Unit Code of 42,000. Any of the HFS summary numbers may be used to exercise the maintainability model.

# HFS HARDWARE BREAKDOWN STRUCTURE

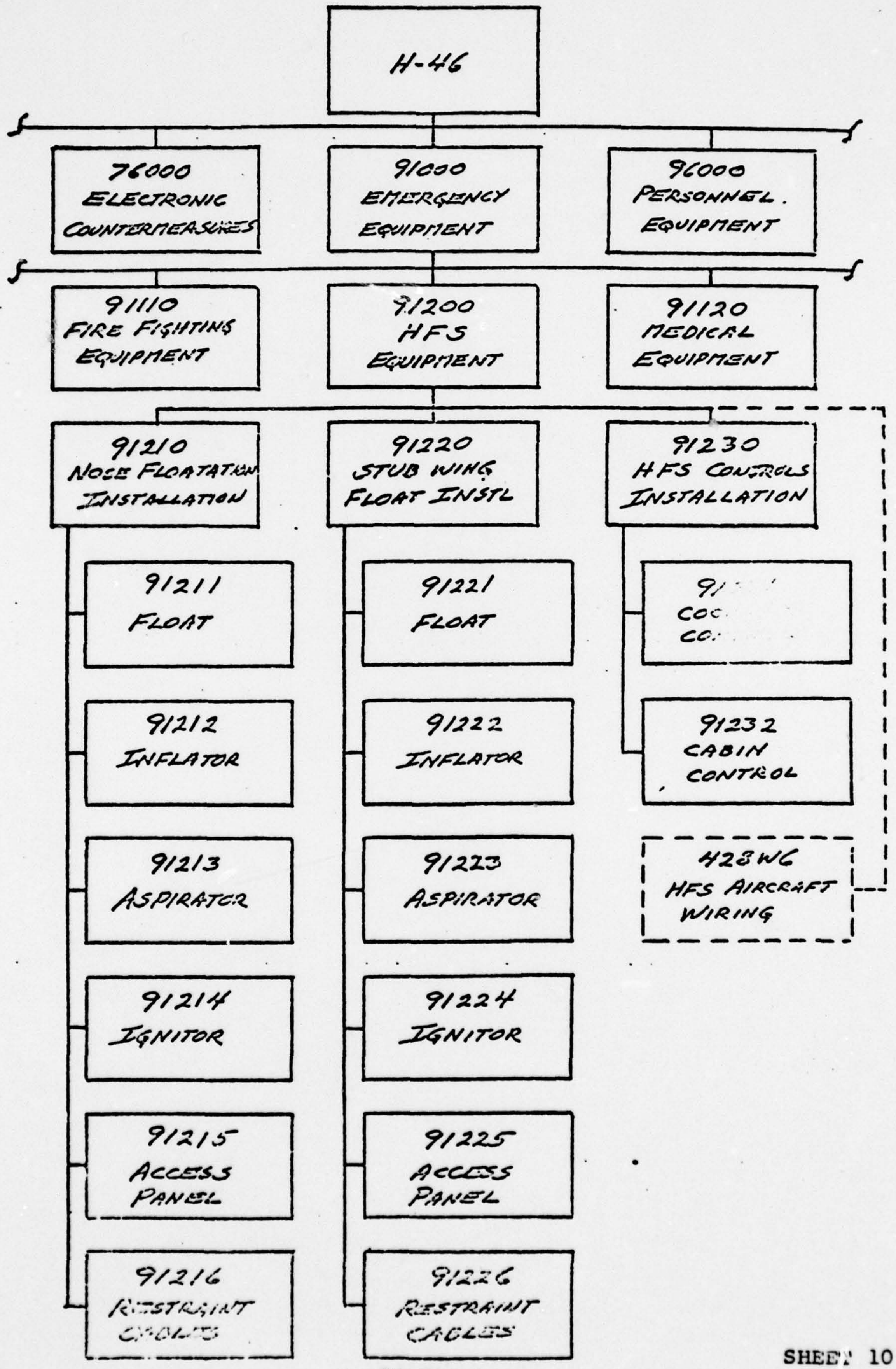



FIGURE 1

## 3. HFS MAINTAINABILITY BLOCK DIAGRAM

The top level maintainability block diagram for the HFS is shown in Figure 2. This diagram indicates what maintenance must be performed and why it is performed. Applying this rationale to lower levels of installation indenture results in the definition of maintainability analysis work packages, i.e. how can maintainability techniques reduce the support burden of required maintenance?

## 4. PLANNED MAINTENANCE

The planned maintenance block of the diagram refers to the planned maintenance requirements of the Naval Aviation Maintenance Program (NAMP) as defined in Chapter 11, Volume II of OPNAVINST 4790.2A. The HFS installation support is based on the requirements of the NAMP. The planned maintenance requirements of the HFS with their rationale are defined in the following paragraphs.

### 4.1 TURNAROUND INSPECTION

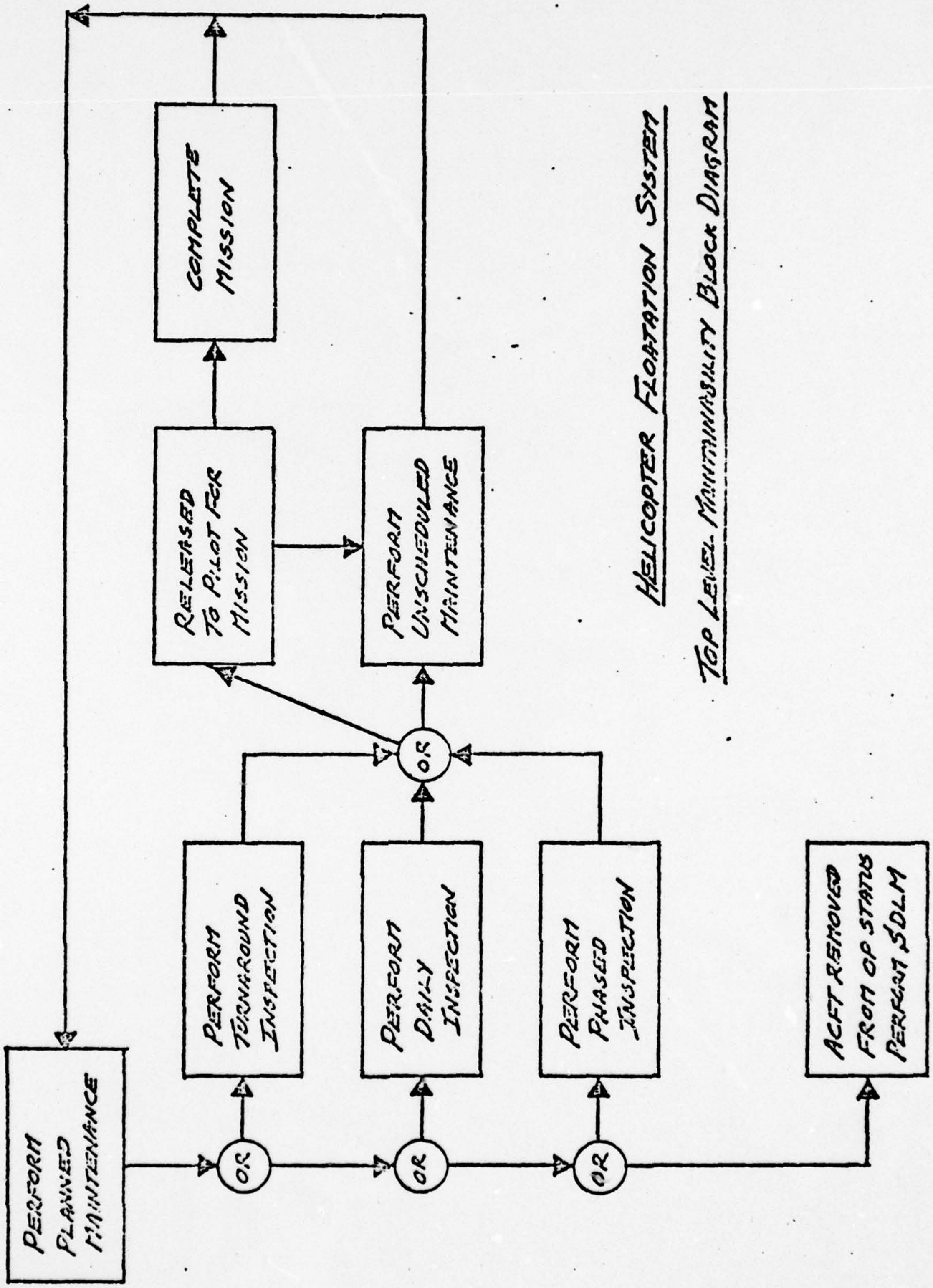
This inspection is conducted to ensure the integrity of the HFS for flight and to detect degradation that may have occurred during the previous flight. The turnaround inspection is performed prior to the first flight of each day and after every flight. Since the HFS has a built in test capability which is exercised as part of the pilot's preflight check list, the turnaround inspection is limited to an external visual inspection of the flotation installations for security and obvious damage.

### 4.2 DAILY INSPECTION

This inspection is conducted to a greater depth than the turnaround inspection. In addition to security and obvious damage, components are inspected for corrosion, wear, and overall condition. The daily inspection is performed prior to the first flight of the day and may be considered valid for a period of 72 hours, provided that no flight occurs during this period and no maintenance other than servicing has been performed.

### 4.3 PHASED INSPECTION

The H-46 helicopter phased inspection is a series of four related inspections that are performed sequentially at 100 hour intervals. One of these phases shall include a comprehensive inspection of the HFS installation. This inspection will check the condition and operation of all HFS components to the extent allowed without inflating the floats. The floats shall be so designed and constructed that inspection will not be required for 24 month periods.




HELICOPTER FLOATATION SYSTEM

TOP LEVEL MAINTAINABILITY BLOCK DIAGRAM

FIGURE 2

### 4.4 STANDARD DEPOT LEVEL MAINTENANCE (SDLM)

SDLM requirements provide for in-depth inspections for material degradation that may have occurred since the last SDLM and include essential preventive maintenance beyond the scope of that performed during the normal periodic inspections. The SDLM interval for the H-46 helicopter is 24 months. During this inspection the floats shall be inflated and tested, and the aircraft is removed from operational status. This inspection is beyond the scope of the maintainability block diagram and mathematical model as specified by MIL-STD-1304A(AS) "Reports: Reliability and Maintainability Engineering Data" but is mentioned to complete the planned maintenance inspection cycle.

### 4.5 CORRECTIVE (UNSCHEDULED) MAINTENANCE

Corrective maintenance is a result of discrepancies noted during planned maintenance or reported by pilots after unsuccessful preflight test. The latter represent an impact on overall H-46 helicopter availability and hence maintainability features of HFS design shall receive special attention in this area.

## 5. MAINTAINABILITY MATHEMATICAL MODEL

Figure 3 is a flow chart of the math model used to derive maintainability quantitative parameters. Abbreviations, constants and variables are defined as follows:

| | |
|---|---|
| WRA | Weapons Replaceable Assembly |
| BCM 9 | Beyond Capability of Intermediate Maintenance (Item condemned) |
| BCM 1-8 | Beyond Capability of Intermediate Maintenance (Item shipped to depot level) |
| MH/FH | Manhours per Flight Hour |
| $\lambda$ | Maintenance action rate per 1000 flight hours |
| ET | Elapsed time in minutes |
| CREW | Average number of men required for the maintenance action |
| TURNAROUND | Performed every two flight hours and $\lambda$ = 500 per 1000 flight hours |
| PHASE | Performed every 400 flight hours and $\lambda$ = 2.5 per 1000 flight hours |
| DAILY | Performed every 3 flight hours and $\lambda$ = 333.3 per 1000 flight hours |

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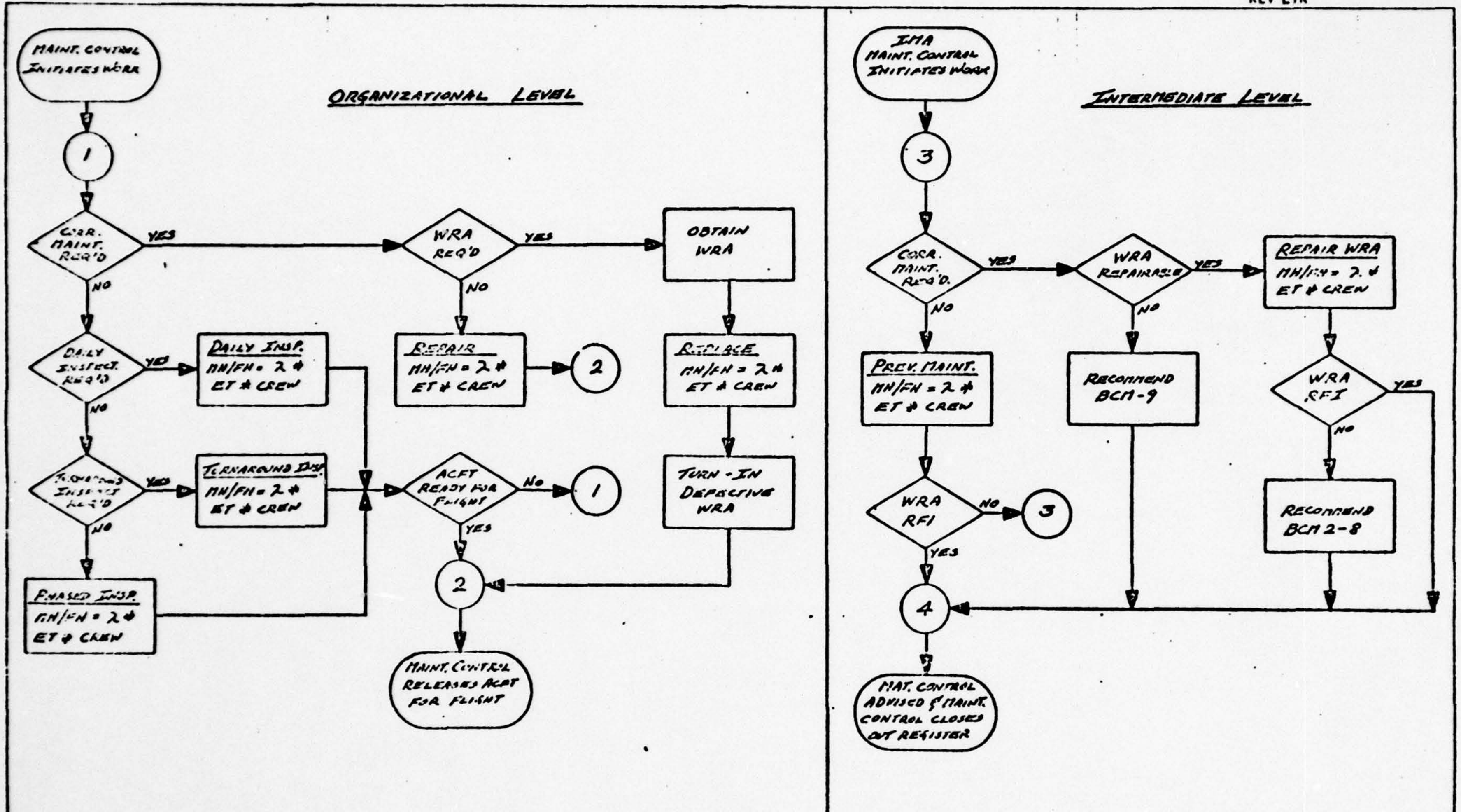


MAINTAINABILITY MODEL - FLOW CHART

FIGURE 3

### 5.1 MAINTENANCE DOWNTIME

HFS preventive maintenance is performed concurrent with existing H-46 preventive maintenance requirements and hence has no effect on aircraft downtime. HFS Mean Maintenance Downtime (MMDT) and Maintenance Downtime per Flight Hour (DT/FH) are computed as follows:

$$MMDT = \frac{((Repair\ \lambda * Repair\ ET) + (Replace\ \lambda * Replace\ ET))}{((Repair\ \lambda + Replace\ \lambda)*60)}$$

$$DT/FH = \frac{((Repair\ \lambda * Repair\ ET) + (Replace\ \lambda * Replace\ ET))}{(1000*60)}$$

### 5.2 ORGANIZATIONAL MAINTENANCE MANHOURS PER FLIGHT HOUR (ORG MH/FH)

ORG MH/FH is a summation of preventive (PREV ORG MH/FH) and corrective (CORR ORG MH/FH) times, and is computed as follows:

PREV ORG MH/FH = ((Turnaround λ * Turnaround ET * Turnaround Crew) + (Daily λ * Daily ET * Daily Crew) + (Phase λ * Phase ET * Phase Crew))/(1000*60)

CORR ORG MH/FH = ((Repair λ * Repair ET * Repair Crew) + (Replace λ * Replace ET * Replace Crew))/(1000*60)

ORG MH/FH = PREV ORG MH/FH + CORR ORG MH/FH

### 5.3 INTERMEDIATE MAINTENANCE MANHOURS PER FLIGHT HOUR (INT MH/FH)

INT MH/FH is also a summation of preventive and corrective time, and is computed as follows:

INT MH/FH = ((Prev λ * Prev ET * Prev Crew) + (Repair WRA λ * Repair WRA ET * Repair WRA Crew))/(1000*60)

## 6. SUMMARY OF RELIABILITY ANALYSIS

The system was analyzed for flight safety, mission, and maintenance malfunction reliabilities. This analysis included predictions, allocations, Failure Mode and Effects Analysis, and test program design. All numerical reliability requirements were met, and no verifiable single failure points were found.

6.1 GENERAL DISCUSSION

Three types of Reliability have been analyzed:

a. Flight Safety Reliability
b. Mission Reliability
c. Maintenance Malfunction Reliability

Flight Safety Reliability is the probability that no hardware failure will cause a catastrophic accident. For the HFS stability system this is essentially equivalent to the deployment of the bag(s) while flying.

For this stability system, Mission Reliability is defined as the probability that the bags would successfully deploy whenever the system was actived.

Maintenance Malfunction Reliability is the probability of no hardware malfunction requiring maintenance action.

The simultaneous analysis of all three types of Reliability is essential to truly optimize the system. For example, additional levels of redundancy tend to improve the first two types of Reliability, but Maintenance Malfunction Reliability is degraded.

6.2 GROUND RULES

The following ground rules were used for design evaluation:

a. No single failure shall cause a flight safety loss.

b. No single failure shall cause a mission loss.

c. The probability of flight safety loss shall be in the "remote" category (Rfs greater than .9999999 or about 10 million hours between hardware failures affecting safety).

d. Mission Reliability shall equal or exceed .90 for 439.65 flight hours (18 calendar months) under field conditions.

e. Mission Reliability shall equal or exceed .98 for one hour bench tests.

f. The system shall have a 90% probability of passing tests designed to demonstrate the requirements of ground rules 4 and 5 at the 90% confidence level.

g. Subject to the above constraints, Maintenance Malfunction Reliability shall be maximized.

### 6.3 DESIGN CHANGE RATIONALE

Preliminary reliability analysis indicated that the system as defined in D210-11003-1 was not capable of meeting the above ground rules. Accordingly, the design was modified to that shown in the schematic of Figure 4. The following are the rationale for these changes:

a. The preliminary Failure Mode and Effects Analysis identified several wiring single failure points for both flight safety and mission (e.g. opens, shorts to power, and shorts to ground).

b. The deploy relay (K1) was a single failure point for both flight safety and mission reliabilities. The preliminary reliability prediction indicated that single squibs - even "Hi-rel" squibs - could not meet the "bench" mission reliability requirement.

c. The control circuitry prior to relay K1 was vulnerable to EMI (electro-magnetic interference) thus defeating the intent of the high amperage squibs.

## 7. RELIABILITY BLOCK DIAGRAMS

Figures 5, 6, 7, and 8 are the Reliability Block Diagrams for Maintenance Malfunction, "bench" Mission, "field" Mission, and Flight Safety Reliabilities respectively. Unless otherwise noted, all numbers are "effective" or "average" failure rates in failures per million hours. Numbers such as .0(8)123 are a short form for .00000000123 (likewise .9(5)123 = .99999123). MIL-STD-756 conventions are applicable.

## 8. RELIABILITY PREDICTIONS

Figure 9 is a computerized reliability prediction for the four different types of reliability. These predictions utilize the logical relationships (redundancies) shown in the Reliability Block Diagrams. All numbers are failure rates in failures per million hours. Converted to reliabilities, the system values are as follows:

| | Failure Rate | Time (Hrs) | Predicted Reliability | Required Reliability |
|---|---|---|---|---|
| Maintenance Malfunction | 1533.100 | 1 | .9(2)846 | |
| "bench" Mission | 426.913 | 1 | .9(3)573 | .98 |
| "field" Mission | .977 | 439.65 | .9(3)570 | .90 |
| Flight Safety | .0(8)175 | 439.65 | .9(12)226 | .9(7) |

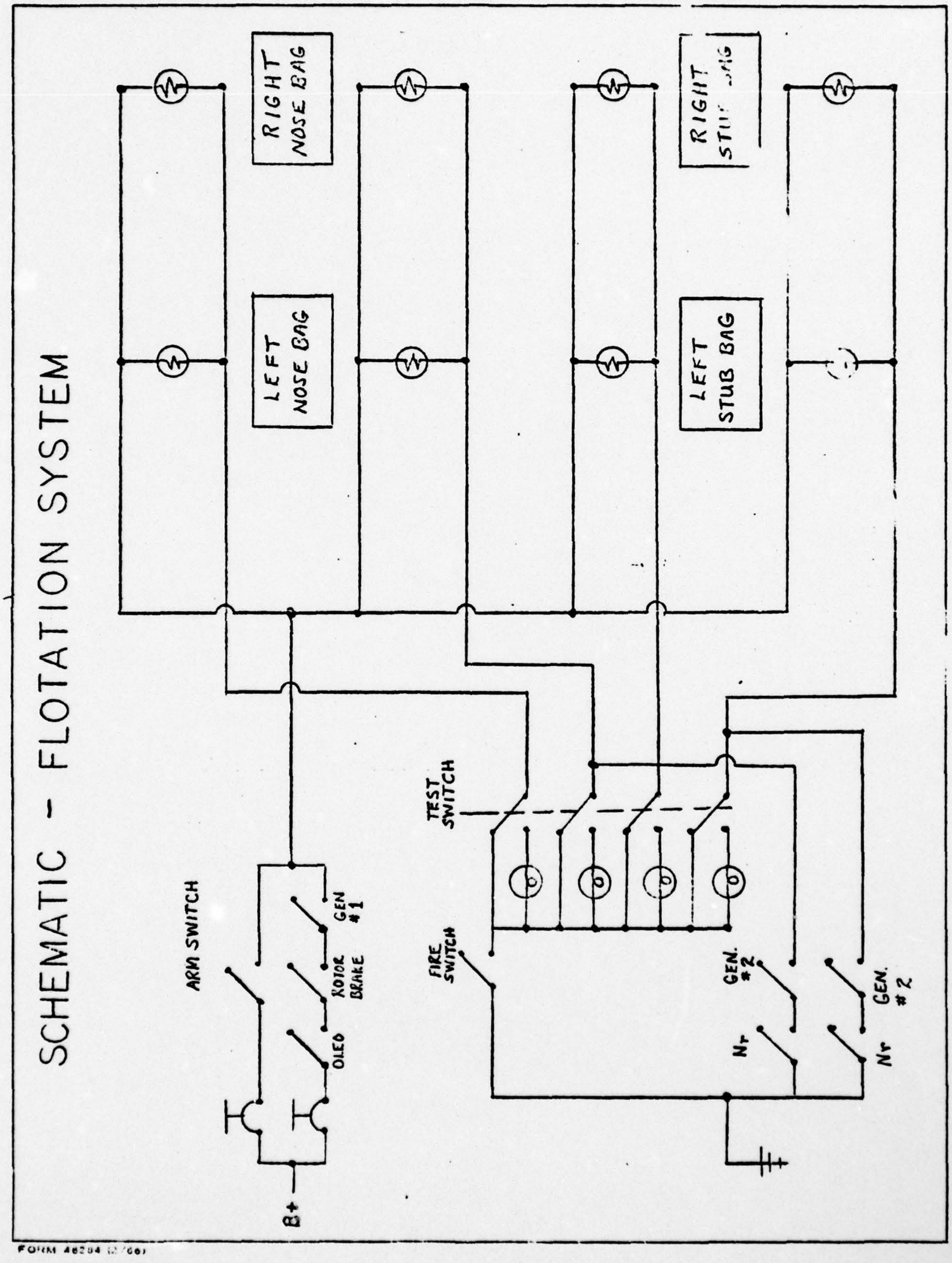
SCHEMATIC - FLOTATION SYSTEM
RIGHT NOSE BAG
LEFT NOSE BAG
LEFT STUB BAG
ARM SWITCH
GEN #1
ROTOR BRAKE
OLEO
TEST SWITCH
FIRE SWITCH
GEN. #2
GEN. #2
Nr
Nr
B+

FIGURE 4

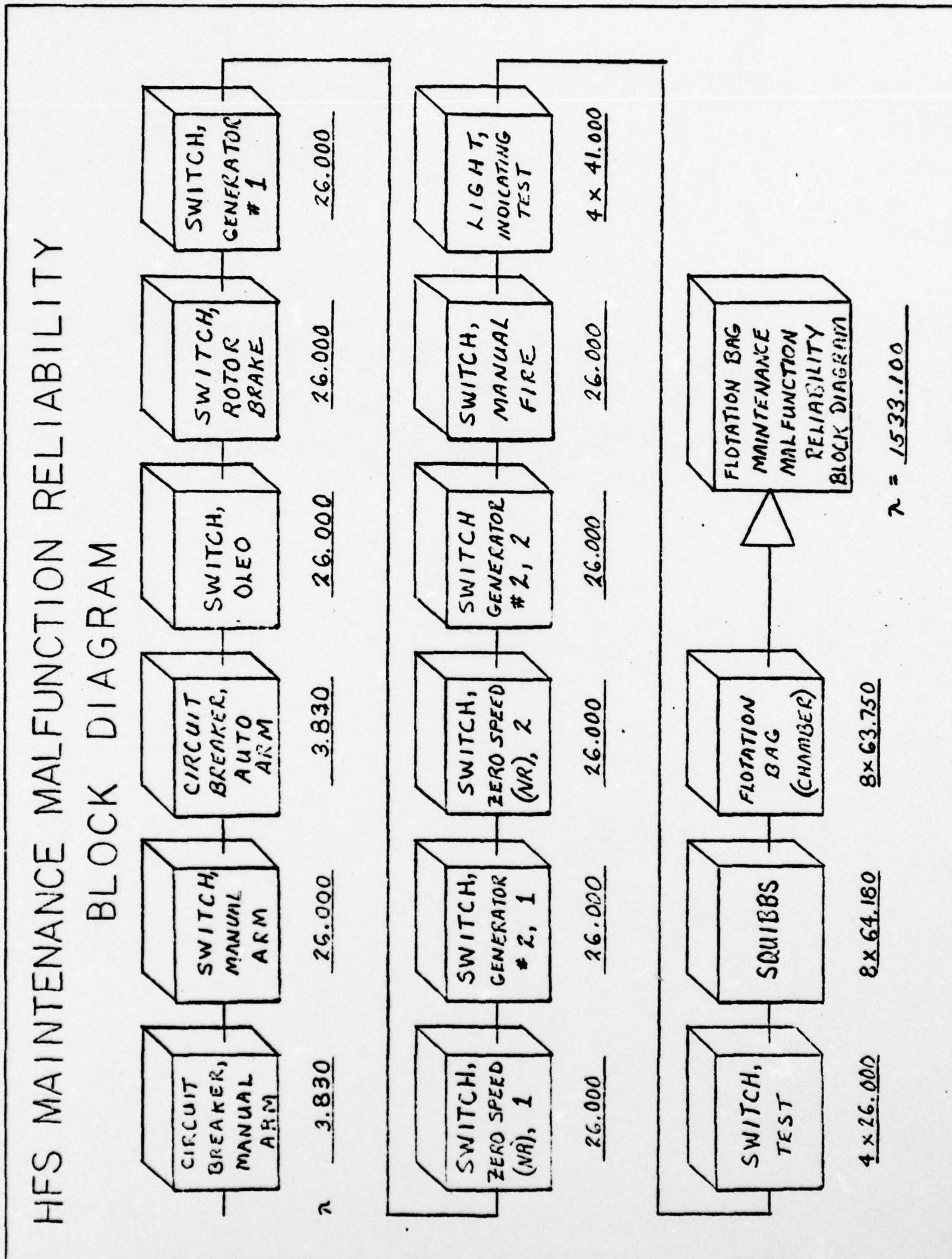
HFS MAINTENANCE MALFUNCTION RELIABILITY
BLOCK DIAGRAM
CIRCUIT BREAKER, MANUAL ARM
SWITCH, MANUAL ARM
CIRCUIT BREAKER, AUTO ARM
SWITCH, OLEO
SWITCH, ROTOR BRAKE
SWITCH, GENERATOR # 1
λ
3.830
26.000
3.830
26.000
26.000
26.000
SWITCH, ZERO SPEED (NR), 1
SWITCH, GENERATOR # 2, 1
SWITCH, ZERO SPEED (NR), 2
SWITCH GENERATOR # 2, 2
SWITCH, MANUAL FIRE
LIGHT, INDICATING TEST
26.000
26.000
26.000
26.000
26.000
4 x 41.000
SWITCH, TEST
SQUIBBS
FLOTATION BAG (CHAMBER)
FLOTATION BAG MAINTENANCE MALFUNCTION RELIABILITY BLOCK DIAGRAM
4 x 26.000
8 x 64.180
8 x 63.750
λ = 1533.100

FIGURE 5

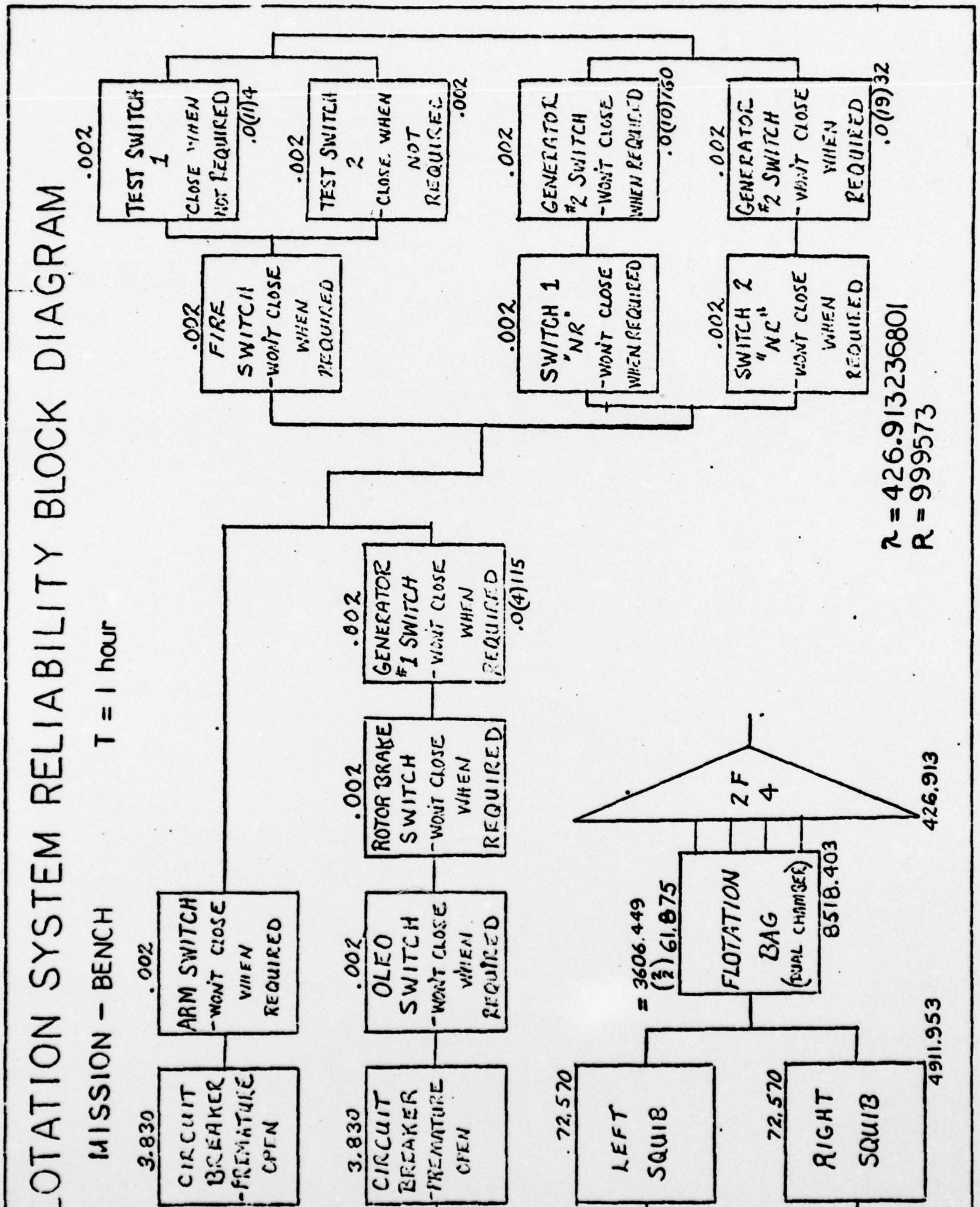


FIGURE 6

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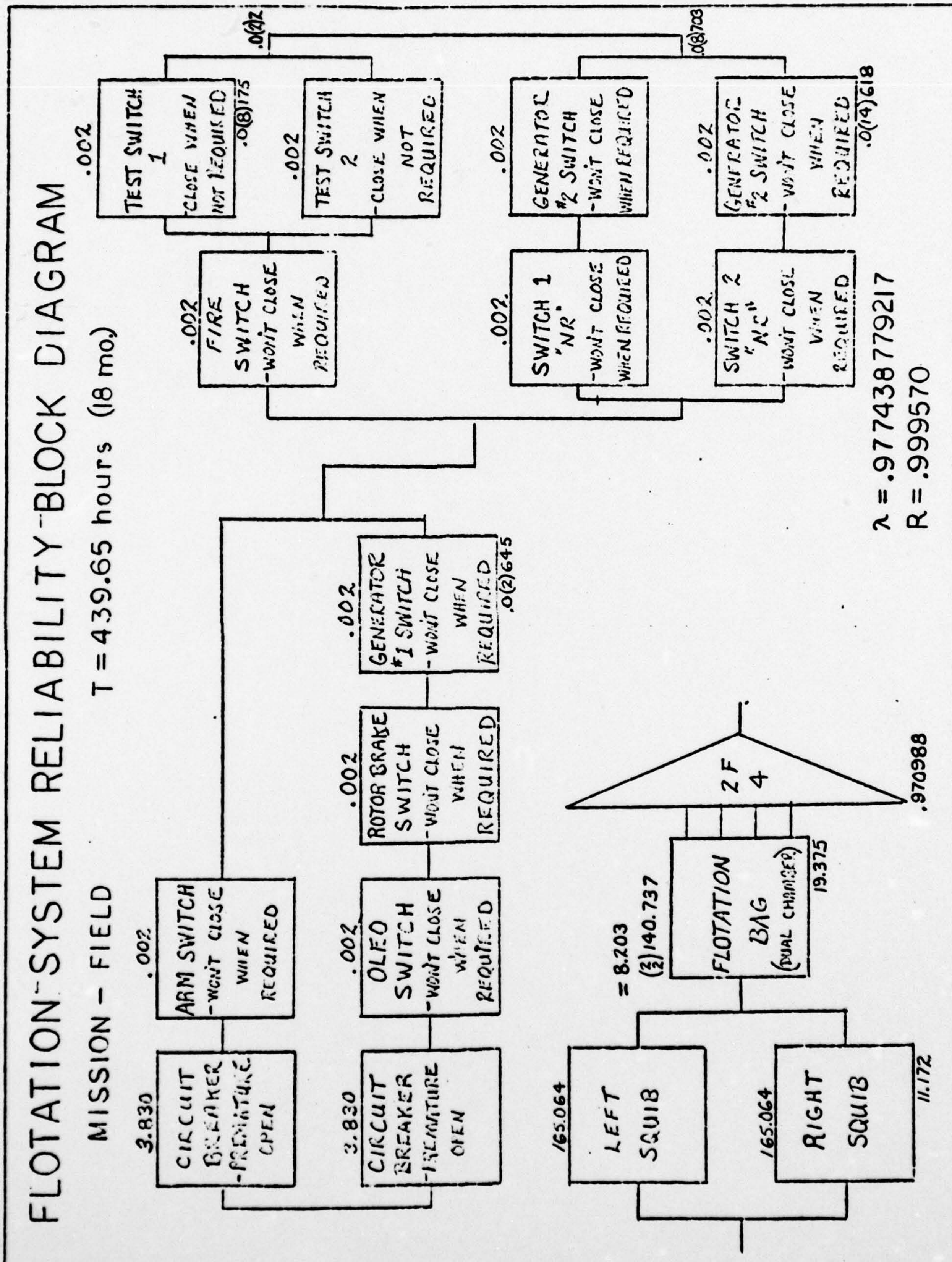
FLOTATION-SYSTEM RELIABILITY-BLOCK DIAGRAM
MISSION - FIELD
T = 439.65 hours (18 mo.)
3.830
CIRCUIT BREAKER -PREMATURE OPEN
.002
ARM SWITCH -WON'T CLOSE WHEN REQUIRED
3.830
CIRCUIT BREAKER -PREMATURE OPEN
.002
OLEO SWITCH -WON'T CLOSE WHEN REQUIRED
.002
ROTOR BRAKE SWITCH -WON'T CLOSE WHEN REQUIRED
.002
GENERATOR #1 SWITCH -WON'T CLOSE WHEN REQUIRED
.0(2)645
.002
FIRE SWITCH -WON'T CLOSE WHEN REQUIRED
.002
TEST SWITCH 1 -CLOSE WHEN NOT REQUIRED
.0(8)175
.002
TEST SWITCH 2 -CLOSE WHEN NOT REQUIRED
.0(2)12
.002
SWITCH 1 "NR" -WON'T CLOSE WHEN REQUIRED
.002
GENERATOR #2 SWITCH -WON'T CLOSE WHEN REQUIRED
.0(8)703
.002
SWITCH 2 "NC" -WON'T CLOSE WHEN REQUIRED
.002
GENERATOR #2 SWITCH -WON'T CLOSE WHEN REQUIRED
.0(14)618
165.064
LEFT SQUIB
165.064
RIGHT SQUIB
11.172
= 8.203
(3)(2)140.737
FLOTATION BAG (DUAL CHAMBER)
19.375
2F
4
.970988
λ = .977438779217
R = .999570

FIGURE 7

# FLIGHT SAFETY RELIABILITY BLOCK DIAGRAM

## FLOTATION SYSTEM

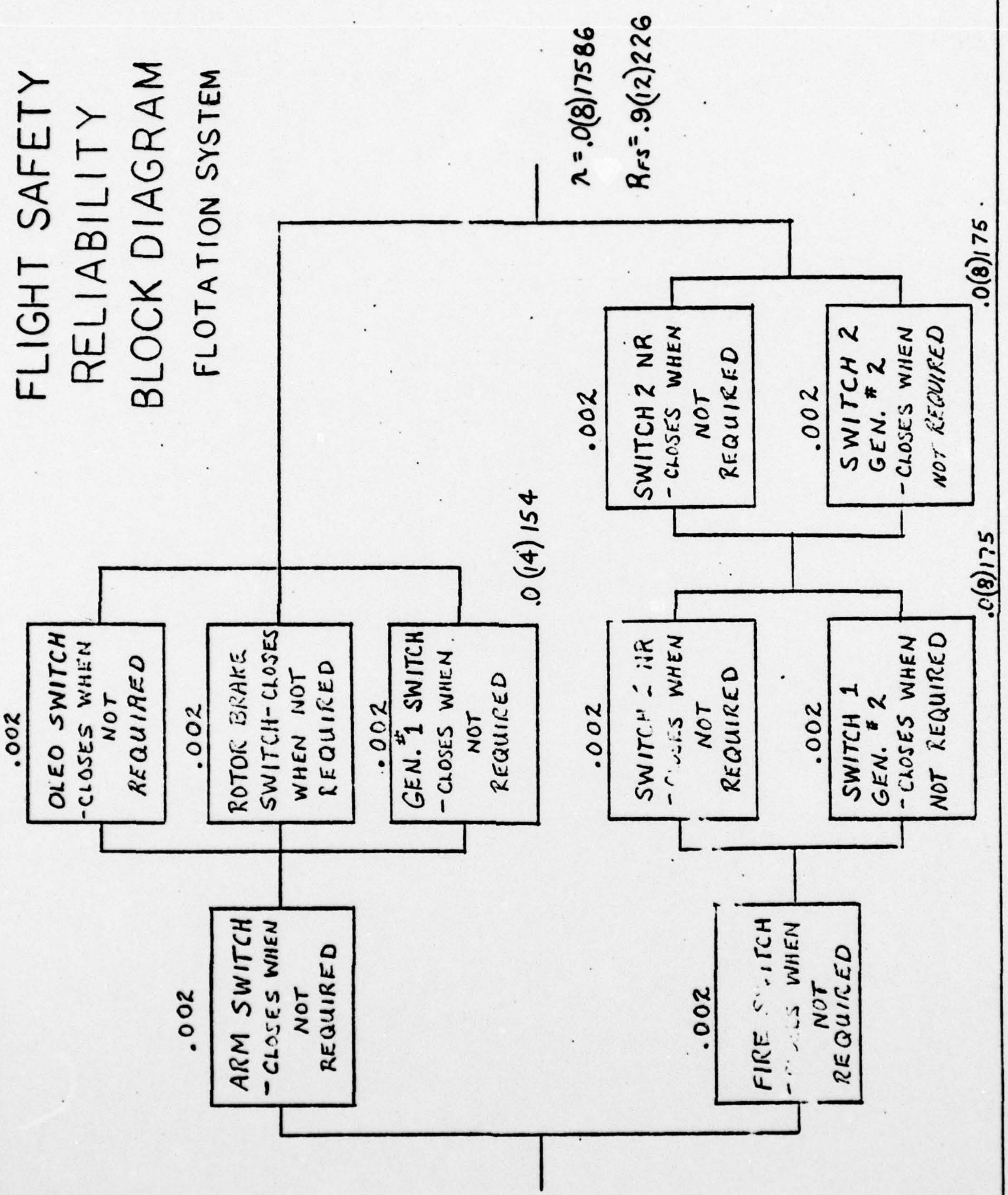


FIGURE 8

The Maintenance Malfunction value indicates an average time of 652 flight hours between maintenance-requiring malfunctions. The remaining reliabilities exceed their requirements by a margin big enough to assure 90% probability of passing a 90% confidence test. These margins are also large enough to assure that a worst case (-3 sigma) deviation would still meet the requirements.

## 9. RELIABILITY ALLOCATIONS

Figure 10 is a computerized reliability allocation for the four different types of reliability. These allocations utilize the logical relationships (redundancies) shown in the Reliability Block Diagrams. All numbers are failure rates in failures per million hours. If the system level predicted failure rate is less than the requirement, the program allocates the predicted values to the components. If the system level predicted failure rate is greater than the requirement, the program allocates the required value to the components in proportion to their relative contribution to the system level prediction (proportioned burden apportionment).

## 10. FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

Figure 11 is a computerized Failure Mode and Effects Analysis (FMEA). "Opens", "shorts", "shorts to power", and "shorts to ground" were analyzed. Since both inputs and outputs were analyzed, wiring failures are also covered. After redesign, no mission single failure points were identified. Auto-ignition of the squibs would be a flight safety single failure point, but we were unable to identify any recorded instance of this mode. The basic technique for protection against shorts to power and shorts to ground is switch disconnection of <u>both</u> power and ground connections. This technique-in conjunction with twisted pair power/ground wiring-gives better protection against EMI firing than is possible with shielded wiring.

## 11. RELIABILITY TEST PROGRAM

The requirements for this program do not specifically call for a Reliability Demonstration Test. However, they do say that:

a. Each system shall be designed for a probability of success (reliability) of .98 at the 90% confidence level for bench testing.

b. Each helicopter system shall be capable of demonstrating a reliability of .90 at the 90% confidence level when completely installed in the subject helicopter.

| | | QTY | MM FR | FIELD FR | BENCH FR | FS FR | NAME | |
|---|---|---|---|---|---|---|---|---|
| 1 | 999 | 1 | | R.977438 | R426.913 | R0. | FLOTATION BAG SYSTEM | |
| | | 1X | 0.0 | 0.977 | 426.913 | 0.0 | SUBTOTAL | |
| 2 | 998 | 1 | | R.00645 | R.0000115 | | 'ARM' CIRCUIT | |
| | | 1X | 0.0 | 0.006 | 0.000 | 0.0 | SUBTOTAL | |
| 3 | 997 | 1 | | | | | MANUAL ARM CIRCUIT | |
| 4 | 69 | 1 | 3.830 | 3.830 | 3.830 | ,0. | BREAKER | ARM |
| 5 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | ARM |
| | | 1X | 29.830 | 3.832 | 3.832 | 0.002 | TOTAL: MANUAL ARM CIRCUIT | |
| 6 | 997 | 1 | | | | R0. | AUTOMATIC ARM CIRCUIT | |
| 7 | 69 | 1 | 3.830 | 3.830 | 3.830 | 3.830 | BREAKER | AUTO |
| 8 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | OLEO |
| 9 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | RTR BRAK |
| 10 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | GEN #1 |
| | | 1X | 81.330 | 3.836 | 3.836 | 0.0 | TOTAL: AUTOMATIC ARM CIRCUIT | |
| | | 1X | 111.660 | 0.006 | 0.000 | 0.002 | TOTAL: 'ARM' CIRCUIT | |
| 11 | 998 | 1 | | R0. | R0. | | 'FIRE' CIRCUIT | |
| 12 | 997 | 1 | | R0. | R0. | R0. | AUTOMATIC FIRE CIRCUIT | |
| 13 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | NR,1 |
| 14 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | GEN#2,1 |
| 15 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | NR,2 |
| [illegible] | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | GEN#2,2 |
| | | 1X | 104.000 | 0.0 | 0.0 | 0.0 | TOTAL: AUTOMATIC FIRE CIRCUI | |
| 17 | 997 | 1 | | R.002 | R.002 | | MANUAL FIRE CIRCUIT | |
| 18 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | FIRE |
| 19 | 79 | 4 | 41. | 40.986 | 40.986 | 0.0 | LIGHT,INDICATE | RIGHT |
| 20 | 75 | 4 | 26. | .002 | .002 | ,0. | SWITCH | TEST,R |
| | | 1X | 294.000 | 0.002 | 0.002 | 0.002 | TOTAL: MANUAL FIRE CIRCUIT | |
| | | 1X | 398.000 | 0.0 | 0.0 | 0.002 | TOTAL: 'FIRE' CIRCUIT | |
| 21 | 998 | 4 | | R.970988 | R426.913 | | 'DEPLOY BAG' CIRCUITS | |
| | | 1X | 0.0 | 0.971 | 426.913 | 0.0 | SUBTOTAL | |
| 22 | 997 | 1 | | R11.172 | R4911.953 | | REDUNDANT SQUIBS | |
| 23 | 145 | 2 | 64.180 | ,165.064 | ,72570. | ,0. | SQUIB | |
| | | 1X | 128.360 | 11.172 | 4911.953 | 0.0 | TOTAL: REDUNDANT SQUIBS | |
| 24 | 997 | 1 | | R8.203 | R3606.449 | | FLOTATION BAG | |
| 25 | 0 | 2 | ,63.75 | ,140.737 | ,61875. | ,0. | FLOTATION BAG CHAMBER | |
| | | 1X | 127.500 | 8.203 | 3606.449 | 0.0 | TOTAL: FLOTATION BAG | |
| | | 4X | 255.860 | 0.971 | 426.913 | 0.0 | TOTAL: 'DEPLOY BAG' CIRCUITS | |
| | | 1X | 1533.100 | 0.977 | 426.913 | 0.0 | TOTAL: FLOTATION BAG SYSTEM | |

FIGURE 9

FAILURE RATE PREDICTION

NOTE:ALL FAILURE RATES = FAILURES PER MILLION HOURS

MM FR : MAINTENANCE MALFUNCTION RATE
M1 FR : FIELD MISSION RELIABILITY FAILURE RATE
M2 FR : BENCH MISSION RELIABILITY FAILURE RATE
FS FR : FLIGHT SAFETY RELIABILITY FAILURE RATE

FIGURE 9 (Continued)

| | | QTY | MM FR | FIELD FR | BENCH FR | FS FR | NAME | |
|---|---|---|---|---|---|---|---|---|
| 1 | 999 | 1 | | R.977438 | R426.913 | R0. | FLOTATION BAG SYSTEM | |
| 2 | 998 | 1 | | R.00645 | R.0000115 | | 'ARM' CIRCUIT | |
| 3 | 997 | 1 | | | | | MANUAL ARM CIRCUIT | |
| | 69 | 1 | 3.830 | 3.830 | 3.830 | ,0. | BREAKER | ARM |
| 5 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | ARM |
| | | 1X | 29.830 | 3.832 | 3.832 | 0.002 | TOTAL: | MANUAL ARM CIRCUIT |
| 6 | 997 | 1 | | | | R0. | AUTOMATIC ARM CIRCUIT | |
| 7 | 69 | 1 | 3.830 | 3.830 | 3.830 | 3.830 | BREAKER | AUTO |
| 8 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | OLEO |
| 9 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | RTR BRAK |
| 10 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | GEN #1 |
| | | 1X | 81.830 | 3.836 | 3.836 | 0.0 | TOTAL: | AUTOMATIC ARM CIRCUIT |
| | | 1X | 111.660 | 0.006 | 0.000 | 0.002 | TOTAL: | 'ARM' CIRCUIT |
| 11 | 998 | 1 | | R0. | R0. | | 'FIRE' CIRCUIT | |
| 12 | 997 | 1 | | R0. | R0. | R0. | AUTOMATIC FIRE CIRCUIT | |
| 13 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | NR,1 |
| 14 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | GEN#2,1 |
| 15 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | NR,2 |
| 16 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | GEN#2,2 |
| | | 1X | 104.000 | 0.0 | 0.0 | 0.0 | TOTAL: | AUTOMATIC FIRE CIRCUIT |
| 17 | 997 | 1 | | R.002 | R.002 | | MANUAL FIRE CIRCUIT | |
| 18 | 75 | 1 | 26. | .002 | .002 | .002 | SWITCH | FIRE |
| 19 | 79 | 4 | 41. | 40.986 | 40.986 | 0.0 | LIGHT,INDICATE | RIGHT |
| 20 | 75 | 4 | 26. | .002 | .002 | ,0. | SWITCH | TEST,R |
| | | 1X | 294.000 | 0.002 | 0.002 | 0.002 | TOTAL: | MANUAL FIRE CIRCUIT |
| | | 1X | 398.000 | 0.0 | 0.0 | 0.002 | TOTAL: | [illegible]' CIRCUIT |
| 21 | 998 | 4 | | R.970988 | R426.913 | | 'DEPLOY BAG' CIRCUITS | |
| 22 | 997 | 1 | | R11.172 | R4911.953 | | REDUNDANT SQUIBS | |
| 23 | 145 | 2 | 64.180 | ,165.064 | ,72570. | ,0. | SQUIB | |
| | | 1X | 128.360 | 11.172 | 4911.953 | 0.0 | TOTAL: | REDUNDANT SQUIBS |
| 24 | 997 | 1 | | R8.203 | R3606.449 | | FLOTATION BAG | |
| 25 | 0 | 2 | ,63.75 | ,140.737 | ,61875. | ,0. | FLOTATION BAG CHAMBER | |
| | | 1X | 127.500 | 8.203 | 3606.449 | 0.0 | TOTAL: | FLOTATION BAG |
| | | 4X | 255.860 | 0.971 | 426.913 | 0.0 | TOTAL: | 'DEPLOY BAG' CIRCUITS |
| | | 1X | 1533.100 | 0.977 | 426.913 | 0.0 | TOTAL: | FLOTATION BAG SYSTEM |

FIGURE 10

## FAILURE RATE ALLOCATION

NOTE: ALL FAILURE RATES = FAILURES PER MILLION HOURS

MM FR : MAINTENANCE MALFUNCTION RELIABILITY FAILURE RATE
M1 FR : FIELD MISSION RELIABILITY FAILURE RATE
M2 FR : BENCH MISSION RELIABILITY FAILURE RATE
FS FR : FLIGHT SAFETY FAILURE RATE

PREDICTIONS:

| | |
|---|---|
| MM = | 1533.100 |
| M1 = | 0.977 |
| M2 = | 426.913 |
| FS = | 0.000000 |

REQUIREMENTS:

| | |
|---|---|
| MM = | 1533.100 |
| M1 = | 239.646 |
| M2 = | 20202.707 |
| FS = | 0.000227 |

FIGURE 10 (Continued)

FAILURE MODE AND EFFECTS ANALYSIS

| NAME | | FAILURE MODE | EFFECT |
|---|---|---|---|
| FLOTATION BAG SYSTEM | | | |
| 'ARM' CIRCUIT | | | |
| MANUAL ARM CIRCUIT | | | |
| BREAKER,CIRCUIT | ARM | -NO OP.WHEN REQD | -WON'T DISCONNECT A SHORT |
| | ARM | -OP.WHEN NOT RQD | -WON'T MANUAL ARM |
| SWITCH | ARM | -SHORT,IN TO OUT | -MANUAL ERRONEOUSLY ARMED |
| | ARM | -OPEN | -WON'T MANUAL ARM |
| | ARM | -GROUNDED | -WON'T ARM(BOTH BREAKERS POP) |
| | ARM | -SHORT TO B+ | -ERRONEOUSLY ARMED |
| AUTOMATIC ARM CIRCUIT | | | |
| BREAKER,CIRCUIT | AUTO | -NO OP.WHEN REQD | -WON'T DISCONNECT A SHORT |
| | AUTO | -OP.WHEN NOT RQD | -WON'T AUTO ARM |
| SWITCH | OLEO | -SHORT,IN TO OUT | -WILL ARM ON LANDING |
| | OLEO | -OPEN | -WON'T AUTO ARM |
| | OLEO | -GROUNDED | -BREAKER POPS ON LANDING |
| | OLEO | -SHORT TO B+ | -WILL ARM ON LANDING |
| SWITCH | RTR BRAK | -SHORT,IN TO OUT | -WILL FIRE ON WATER SHUTDOWN |
| | RTR BRAK | -OPEN | -WON'T AUTO ARM |
| | RTR BRAK | -GROUNDED | -BREAKER POPS ON LANDING |
| | RTR BRAK | -SHORT TO B+ | -ARMS ON SHUTDOWN |
| SWITCH | GEN #1 | -SHORT,IN TO OUT | -PARTIAL AUTO ARM |
| | GEN #1 | -OPEN | -WON'T AUTO ARM |
| | GEN #1 | -GROUNDED | -POPS BREAKER ON WATER LANDING OR TEST |
| | GEN #1 | -SHORT TO B+ | -ERRONEOUSLY ARMED |
| 'FIRE' CIRCUIT | | | |
| AUTOMATIC FIRE CIRCUIT | | | |
| SWITCH | NR,1 | -SHORT,IN TO OUT | -PART.CLOSURE,NOSE BAG AUTO FIRE CIRCUIT |
| | NR,1 | -OPEN | -1/2 NOSE BAG SQUIBS WON'T AUTO FIRE |
| | NR,1 | -GROUNDED | -1/2 NOSE BAG SQUIBS FIRE ON SHUTDOWN |
| | NR,1 | -SHORT TO B+ | -ELECTRICAL SHORT ON SHUTDOWN |
| SWITCH | GEN#2,1 | -SHORT,IN TO OUT | -PART.CLOSURE,NOSE BAG AUTO FIRE CIRCUIT |
| | GEN#2,1 | -OPEN | -1/2 NOSE BAG SQUIBS WON'T AUTO FIRE |
| | GEN#2,1 | -GROUNDED | -1/2 NOSE BAG SQUIBS FIRE ON SHUTDOWN |
| | GEN#2,1 | -SHORT TO B+ | -ELECTRICAL SHORT ON SHUTDOWN |
| SWITCH | NR,2 | -SHORT,IN TO OUT | -PART.CLOSURE,NOSE BAG AUTO FIRE CIRCUIT |
| | NR,2 | -OPEN | -1/2 NOSE BAG SQUIBS WON'T AUTO FIRE |
| | NR,2 | -GROUNDED | -1/2 NOSE BAG SQUIBS FIRE ON SHUTDOWN |
| | NR,2 | -SHORT TO B+ | -ELECTRICAL SHORT ON SHUTDOWN |
| SWITCH | GEN#2,2 | -SHORT,IN TO OUT | -PART.CLOSURE,STUB BAG AUTO FIRE CIRCUIT |
| | GEN#2,2 | -OPEN | -1/2 STUB BAG SQUIBS WON'T FIRE |
| | GEN#2,2 | -GROUNDED | -1/2 STUB BAG SQUIBS FIRE ON SHUTDOWN |
| | GEN#2,2 | -SHORT TO B+ | -ELECTRICAL SHORT ON SHUTDOWN |
| MANUAL FIRE CIRCUIT | | | |
| SWITCH | FIRE | -SHORT,IN TO OUT | -WILL FIRE IF ARMED |
| | FIRE | -OPEN | -WON'T MANUAL FIRE |
| | FIRE | -GROUNDED | -WON'T MANUAL FIRE |
| | FIRE | -SHORT TO B+ | -WILL FIRE IF ARMED |
| LIGHT,INDICATE | | -SHORT,IN TO OUT | -WILL FIRE SQUIBS IN TEST |
| LIGHT,INDICATE | | -OPEN | -WON'T INDICATE ON TEST |
| LIGHT,INDICATE | | -GROUNDED | -WON'T INDICATE ON TEST |
| LIGHT,INDICATE | | -SHORT TO B+ | -ERRONEOUS INDICATION ON TEST |
| SWITCH | TEST | -SHORT,IN TO OUT | -WON'T TEST SQUIBS |
| | TEST | -OPEN | -WON'T MANUAL FIRE/TEST SQUIBS |
| | TEST | -GROUNDED | -WILL FIRE IF ARMED |
| | TEST | -SHORT TO B+ | -1/2 SQUIBS WON'T FIRE WHEN COMMANDED |
| 'DEPLOY BAG' CIRCUITS | | | |
| REDUNDANT SQUIBS | | | |
| SQUIB | | -NO OP.WHEN REQD | -NO EFFECT(OTHER SQUIBS WILL FIRE) |
| SQUIB | | -OP.WHEN NOT RQD | -SINGLE FAILURE POINT(NO RECORDED OCCUR. |
| FLOTATION BAGS | | | |
| FLOTATION BAG CHAMBER | | -NO OP.WHEN REQD | -1/2 BAG BUOYANCY LOST |
| | | -OP.WHEN NOT RQD | -CAN'T OCCUR BY ITSELF |

FIGURE 11

These require that a test program be designed so that the system would be capable of passing such a test <u>if it were run</u>. MIL-STD-781 gives test plans which demonstrate at 90% (and other) levels of confidence, but this, by itself, is insufficient to respond to the above requirements! The reason is that high confidence tests (such as MIL-STD-781) are so powerful in rejecting <u>bad</u> equipment (less than the requirement) that it also has a high probability of rejecting good equipment! For example take requirement a. above (R of .98 at 90% confidence). Figure 9 shows that if you were to conduct a test of 114 components (or systems) with no failures, you would demonstrate a reliability of .98 at the 90% confidence level. Now suppose you entered this test with 114 components with a <u>true</u> reliability of exactly .98? You would find that you have only a 10% chance of passing the test.* In other words, if you repeated this test a number of times, an average of 9 out of 10 tests would "flunk" (have one or more failures). It turns out that just to have a 50-50 chance of passing the test, you must go into the test with a <u>true</u> reliability of .99394, even though the requirement was only .98. In fact, in order to have a good (e.g. 90%) probability of passing the test, you must go into the test with a true reliability of .999076! In order to better understand what this means, consider the "mean time between failure" or MTBF. A reliability of .98 for a one hour mission is equivalent to an MTBF of 50 hours. A reliability of .99394 is equivalent to an MTBF of 164 hours! A reliability of .999076 is equivalent to an MTBF of 1,081 hours! Thus, the <u>true</u> MTBF must be 22 times greater than the <u>required</u>-just to have a reasonably good probability of passing the test! The probability of <u>not</u> passing the test is usually referred to as "producer's risk" (although it should be realized that in the long run, the consumer actually pays for it). Thus, producer's risk is the probability of rejecting good equipment. One minus the confidence (as a decimal) is equivalent to "consumer's risk" ( risk of accepting bad equipment). The convention is to set up a "fair" testing program (consumer's risk equals producer's risk or probability of passing equals confidence), and Figure 12 shows the results for requirement a. Note that by increasing the number of allowable failures (<u>and</u> the number of tests!) the "true" or designed reliability can be lowered. Obviously there is a practical limit to this approach. Even if we were to increase the number of allowable failures to 52, the design reliability would still have to be .9859 or an MTBF of 70 hours which is still 142% of the required MTBF of 50 hours. Furthermore, the destructive testing of 3,121 systems is probably impractical from both the time and cost standpoint. Thus a balance must be struck between the designed (true) reliability and the number of tests. If we use the reliability prediction

* The theoretical error in this statement is recognized but is not significant to the conclusions developed.

as an estimate of the true reliability, the bench mission prediction of R = .999573 allows selection of the "zero failure in 114 tests" test program. If we allow for an "order of magnitude" error in the prediction: R = .99573, the test program must become "3 or less failures in 333 tests" because this is the smallest program with a 90% probability of passing. It should be noted that this is the primary reason why the design was not frozen when the prediction first reached R = .98. Figure 13 is an equivalent table for the "field" mission and the predicted value of R = .999570 allows the selection of the "zero failure in 22 tests" test program. The time value of 439.65 flight hours was based on 18 months on each of 275 aircraft-the test being an actual firing of the system just prior to refurbishment. This approach would assure testing under field conditions and avoid the cost of special purchases and flights strictly for test purposes.

## 11.1 DEVELOPMENT (PROBLEM IDENTIFICATION) TESTING

The primary reliability testing program will be problem identification testing. The purpose of this type of testing is confirmation of failure effects as identified by the FMEA. Specifically, each FMEA failure mode is artificially induced into the system and the resulting system effect is noted. In addition, system level interface failures are induced to confirm the logic of the Reliability Block Diagrams. Due to the artificial creation of failure modes, no attempt will be made to calculate failure rates based on this data.

# BENCH TEST TRADEOFF FACTORS (T = 1 hour)

R = .98 at 90% CONFIDENCE

| F | N | CONF | $R_T$ for 90% PA | $\theta_T$ for 90% PA | $\theta_T / \theta_{REQ.}$ |
|---|---|---|---|---|---|
| 0 | 114 | .900052340 | .999076211913 | 1081 | 21.857 |
| 1 | 194 | .901537749 | .997255382158 | 363 | 7.35 |
| 2 | 265 | .900767174 | .995854125243 | 239 | 4.83 |
| 3 | 333 | .901013472 | .994750522908 | 189 | 3.83 |
| 4 | 398 | .900376362 | .993875867736 | 162 | 3.28 |
| 5 | 462 | .900445362 | .993163995696 | 145 | 2.94 |
| 6 | 525 | .900683558 | .992566446051 | 134 | 2.70 |
| 7 | 587 | .900820515 | .992052023213 | 125 | 2.50 |
| 8 | 648 | .900712301 | .991599865926 | 118 | 2.39 |
| 9 | 708 | .900278402 | .991195511927 | 113 | 2.28 |
| 10 | 768 | .900326168 | .990840577415 | 108 | 2.19 |
| 11 | 828 | .900743787 | .990526071941 | 105 | 2.122 |
| 12 | 887 | .900655707 | .990234073642 | 101 | 2.058 |
| 13 | 945 | .900072198 | .789960418216 | 99 | 2.002 |
| 14 | 1004 | .900508008 | .989722410528 | 96 | 1.95 |
| 15 | 1062 | .900395702 | .989495604861 | 95 | 1.91 |
| 16 | 1120 | .900471098 | .989287717493 | 93 | 1.87 |
| 17 | 1177 | .900008799 | .989087059036 | 91 | 1.84 |
| 18 | 1235 | .900393622 | .988910475147 | 90 | 1.81 |
| 19 | 1292 | .900226420 | .988737963352 | 88 | 1.78 |
| 20 | 1349 | .900184588 | .988577331437 | 87 | 1.75 |
| 21 | 1406 | .900252322 | .958427320314 | 86 | 1.73 |
| 22 | 1463 | .900416092 | .988286846707 | 85 | 1.71 |
| 23 | 1519 | .900047861 | .988147162327 | 84 | 1.69 |
| 24 | 1576 | .900381900 | .988023277275 | 83 | 1.68 |
| 25 | 1632 | .900186043 | .987899031559 | 82 | 1.65 |
| 26 | 1688 | .900067815 | .987781583449 | 81 | 1.64 |
| 27 | 1744 | .900019697 | .987670356208 | 81 | 1.63 |
| 28 | 1800 | .900034980 | .987564838074 | 80 | 1.61 |
| 29 | 1856 | .900107666 | .987464573150 | 79 | 1.60 |
| 30 | 1912 | .900232379 | .987369154216 | 79 | 1.59 |
| 31 | 1968 | .900404286 | .987278215991 | 78 | 1.58 |
| 32 | 2023 | .900092296 | | | |
| 33 | 2079 | .900344009 | | | |
| 34 | 2134 | .900117755 | | | |
| 35 | 2190 | .900454658 | .986941227070 | 76 | 1.54 |
| 36 | 2245 | .900310661 | | | |
| 37 | 2300 | .900205978 | .986787361413 | 75 | 1.52 |
| 38 | 2355 | .900137880 | | | |
| 39 | 2410 | .900103852 | | | |
| 40 | 2465 | .900101572 | | | |
| 41 | 2520 | .900124893 | | | |
| 42 | 2575 | .900183829 | | | |
| 43 | 2630 | .900264545 | | | |
| 44 | 2685 | .900[illegible]319 | | | |
| 45 | 2739 | .900032677 | | | |
| 46 | 2794 | .900175911 | | | |
| 47 | 2849 | .900[illegible]712 | | | |
| 48 | 2903 | .900[illegible]000 | | | |
| 49 | 2958 | .900311777 | | | |
| 50 | 3012 | .900[illegible]45 | .9860 | 71 | 1.43 |
| 51 | 3067 | .900[illegible] | | | |
| 52 | 3121 | .900173781 | .9857 | 70 | 1.42 |



FIGURE 12

# FIELD TEST TRADE-OFF REQUIREMENTS

R=.90 at 90% CONFIDENCE

| F | N | CONF | $R_T$ for = RISK |
|---|---|---|---|
| 0 | 22 | .901522909 | .995 22233518 |
| 1 | 38 | .904704869 | .98591697 |
| 2 | 52 | .903366714 | .978619 |
| 3 | 65 | .900447174 | .97289 |
| 4 | 78 | .900605676 | .9684915 |
| 5 | 91 | .902424110 | .9656[illegible]287417 |
| 6 | 104 | .905164016 | .96216118 |
| 7 | 116 | .903612658 | .959444555 |
| 8 | 128 | .902872620 | .95712 1541 |
| 9 | 140 | .902736185 | .95510 8963191 |
| 10 | 150 | .903054246 | .953345683172 |
| 11 | 164 | .903717433 | .951785804859 |
| 12 | 175 | .900568851 | .950107901560 |
| 13 | 187 | .901858866 | .948868900485 |
| 14 | 199 | .903294126 | .947748429032 |
| 15 | 210 | .901107564 | .945473106936 |
| 16 | 222 | .902876028 | .945550814046 |
| 17 | 233 | .901140383 | .944464711760 |
| 18 | 245 | .903125862 | .943691216365 |
| 19 | 256 | .901737086 | .942750787225 |
| 20 | 267 | .900509799 | .941874571825 |
| 21 | 279 | .902743287 | .941269030307 |
| 22 | 290 | .901757058 | .940496630841 |
| 23 | 301 | .900887839 | .939771191198 |
| 24 | 312 | .902130924 | .939088324846 |
| 25 | 324 | .902558997 | .938635798233 |
| 26 | 335 | .901953607 | .938022525676 |
| 27 | 346 | .901430670 | .937441789598 |
| 28 | 357 | .900983376 | .93689090[illegible]3 |
| 29 | 368 | .900605570 | |
| 30 | 379 | .900291681 | .935869528855 |
| 31 | 390 | .900036657 | .935394969669 |



FIGURE 13